

***In Situ* Burning for Oil Spills in Ice-covered Waters**

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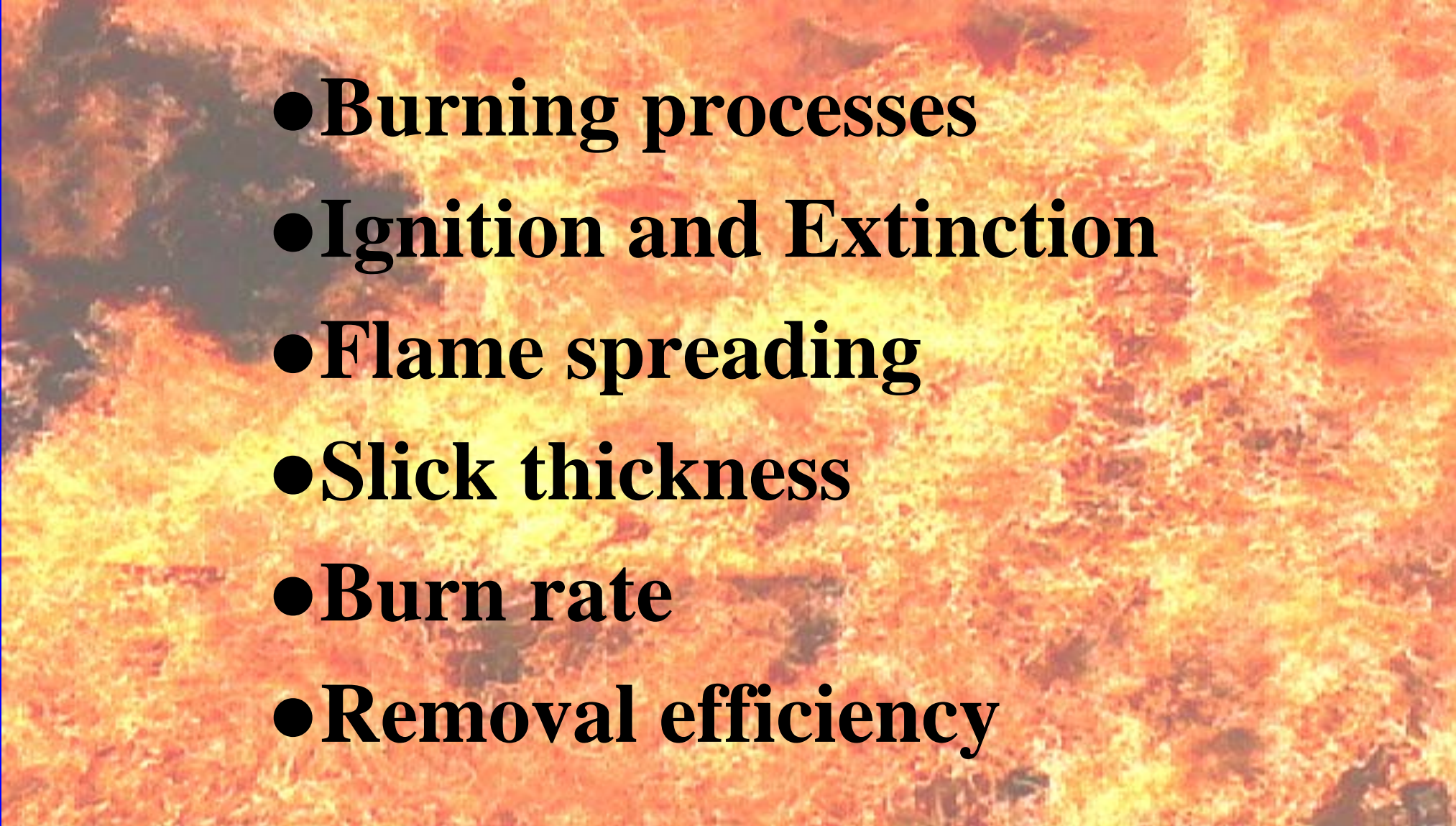
SL Ross Environmental Research



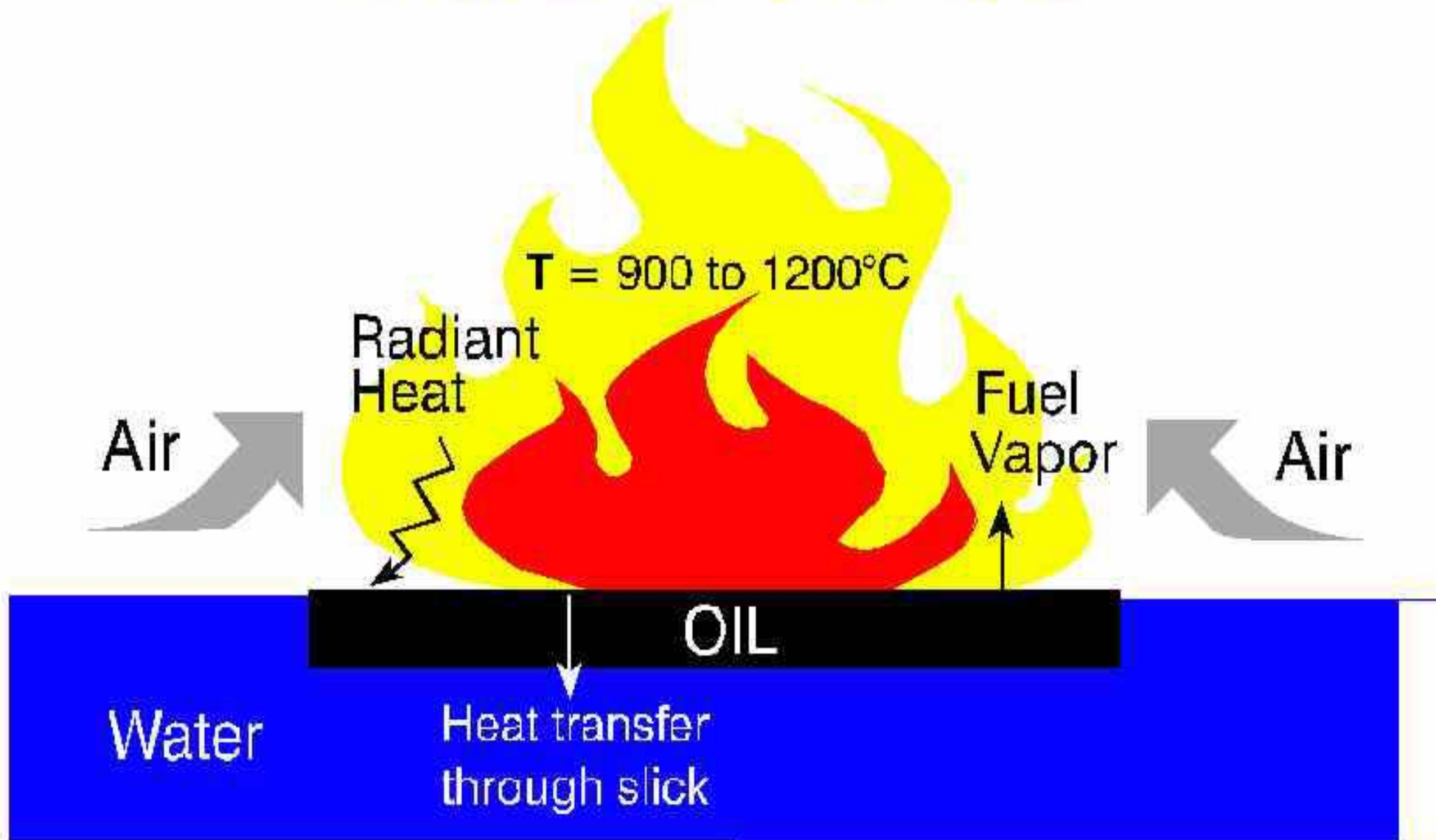
Brief History

- ISB has been studied since late '60s (*Torrey Canyon*) as a countermeasure for oil spills
- Much early work in 1970s and early 80s was on applications in Arctic waters
- With development of fire-resistant booms in mid-to late-80s came serious consideration of ISB in open water
- Work in 90s focused on extending window of opportunity through igniter and fire boom improvements

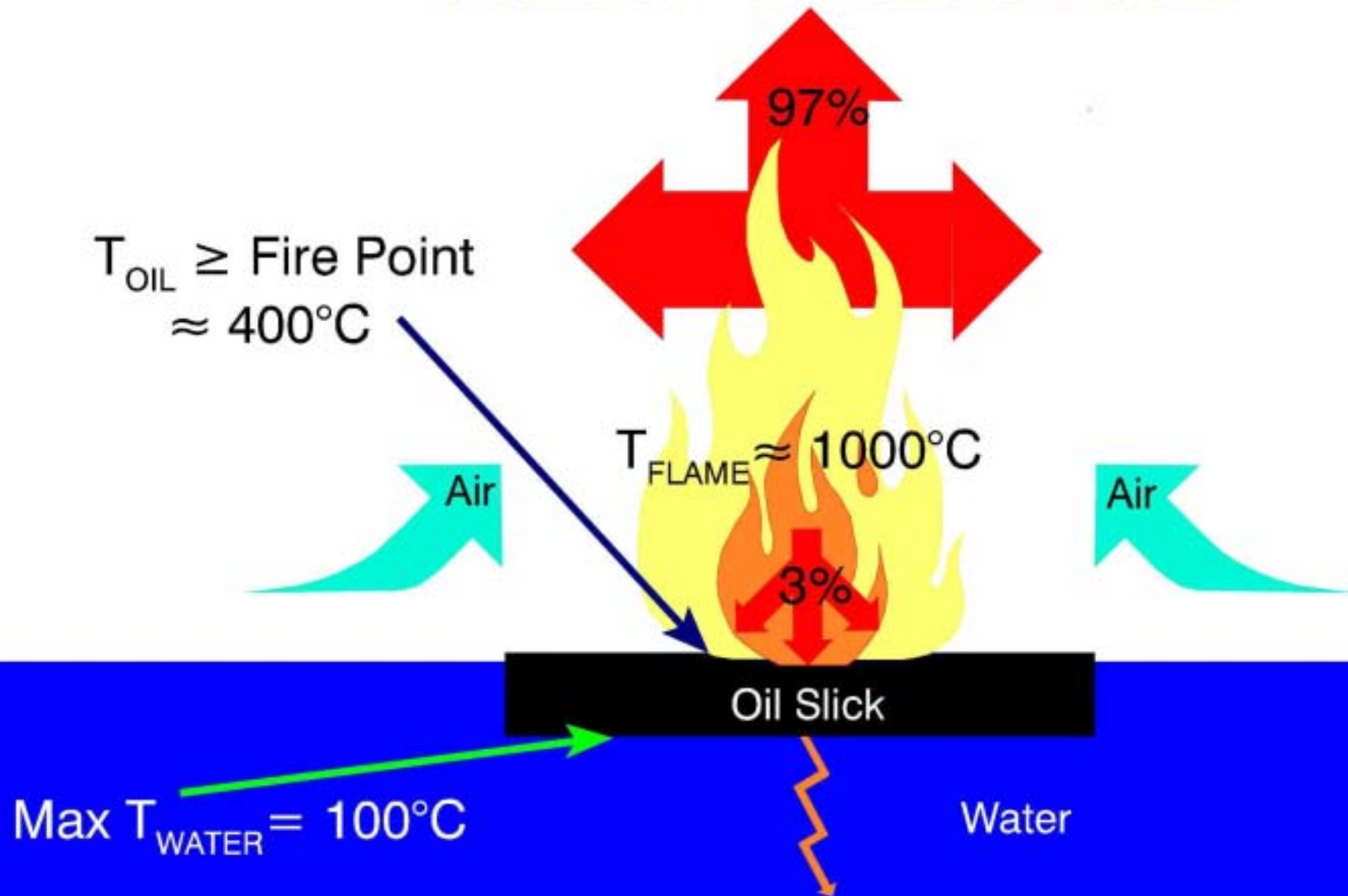
Quick Review: The Basics of ISB on Water

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- A close-up, high-contrast image of a fire, showing bright yellow and orange flames with dark, smoky areas. The texture is grainy and intense, filling the background of the slide.
- **Burning processes**
 - **Ignition and Extinction**
 - **Flame spreading**
 - **Slick thickness**
 - **Burn rate**
 - **Removal efficiency**

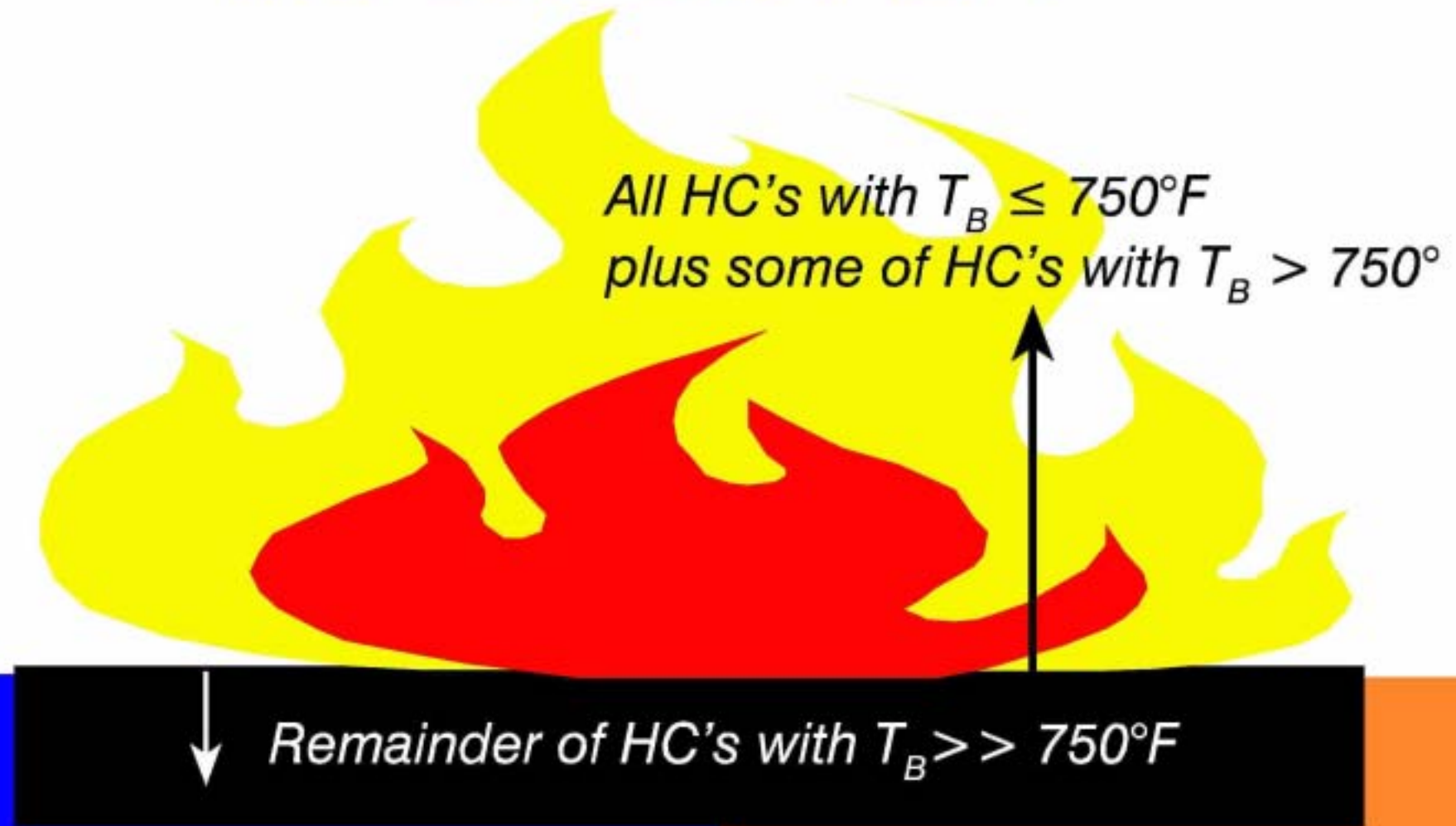
BASIC PROCESS



HEAT BALANCE

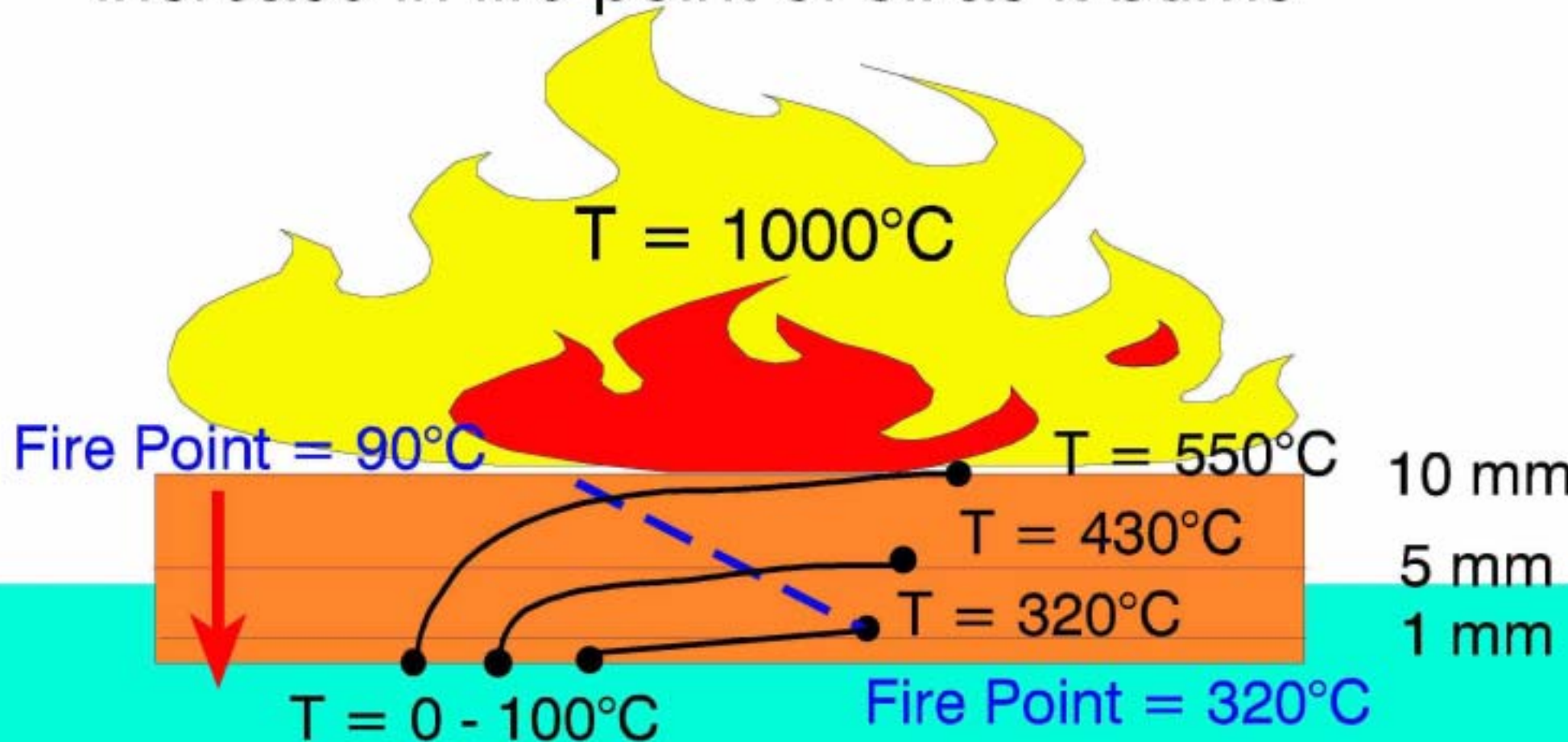


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For Extinction

- determined by heat transfer through slick and increase in fire point of oil as it burns



Slick Thickness

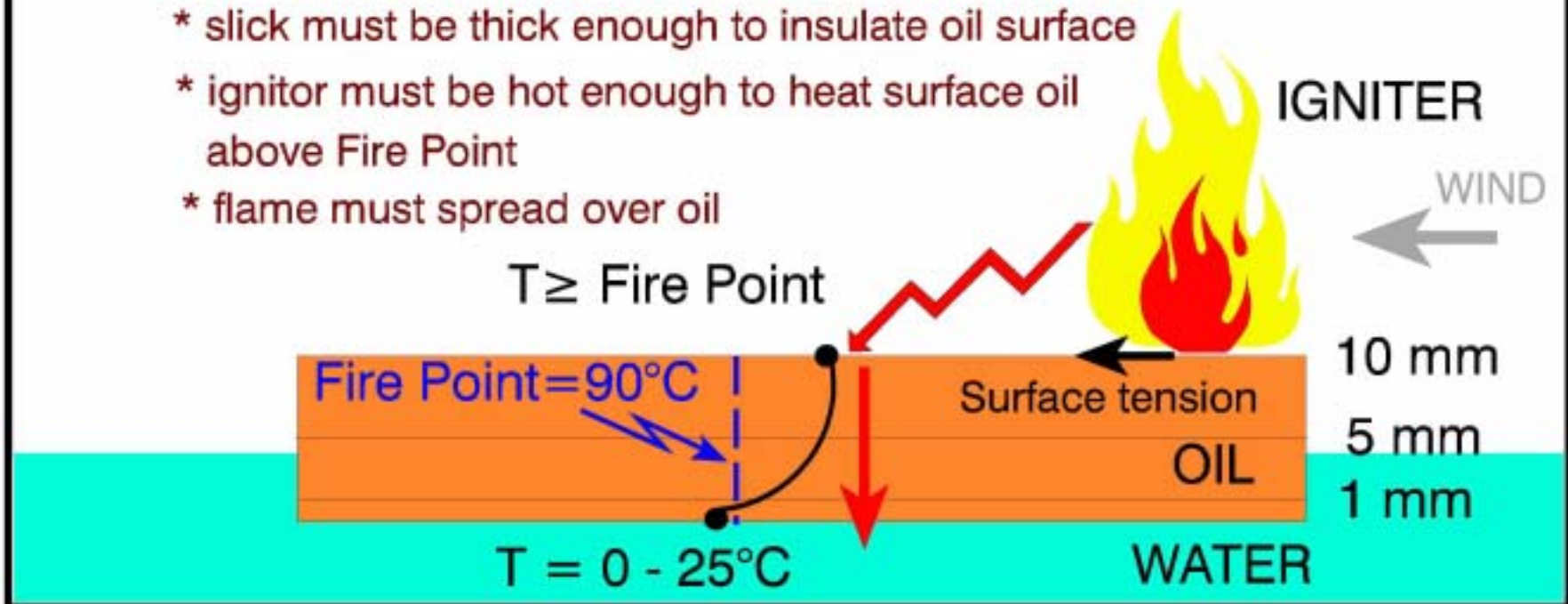
- Most important variable for *in situ* burning
- Thick slick insulates surface oil from cold water
- Allows high surface temperatures to develop
- As burning slick thins, more heat transfers to water
- Eventually cools surface to below Fire Point and extinguishes

PROCESSES GOVERNING IGNITION

- determined by heat transfer through slick and fire point of oil

FOR SUCESSFUL IGNITION TO OCCUR:

- * slick must be thick enough to insulate oil surface
- * ignitor must be hot enough to heat surface oil above Fire Point
- * flame must spread over oil



Rules of Thumb: Minimum Thickness for Ignition on Water

- Fresh crude oil = 1 mm
- Weathered crude, diesel (no emulsion) = 2 to 3 mm
- Residual fuel oils (IFO 380 aka No. 6) = 10 mm
- Emulsions = 10+mm

Flame Spreading

- Critical for efficiency
- Flame spreading slower with:
 - Increasing evaporation (fewer light ends)
 - Thinner slicks (less insulation)
 - Increasing water content
- Flame spreading faster with increasing wind, (but little crosswind spreading)
- Steep/choppy waves reduce flame spreading

SINTEF 2007 Burns on Landfast Ice



Rules of Thumb: Oil Removal Rates on Water

- Strong function of size of fire up to 3 to 5 m
- Weaker function of oil type and thickness
- For large crude oil fires (in boom) = 3.5 mm/min
- Lighter fuels burn slightly faster (diesel = 4 mm/min, gasoline = 4.5 mm/min)
- For small fires (melt pools) = 1 mm/min

Burn Efficiency and Extinction

- Residue remaining:
 - 1 mm for crude oil up to 20 mm thick
 - Thicker residue for thicker slicks (3 to 5 mm for 50 mm)
 - Thicker for residual fuels and emulsions
 - 1 mm for distilled fuels
- Removal efficiency function of:
 - Initial slick thickness
 - Residue thickness
 - Flame coverage

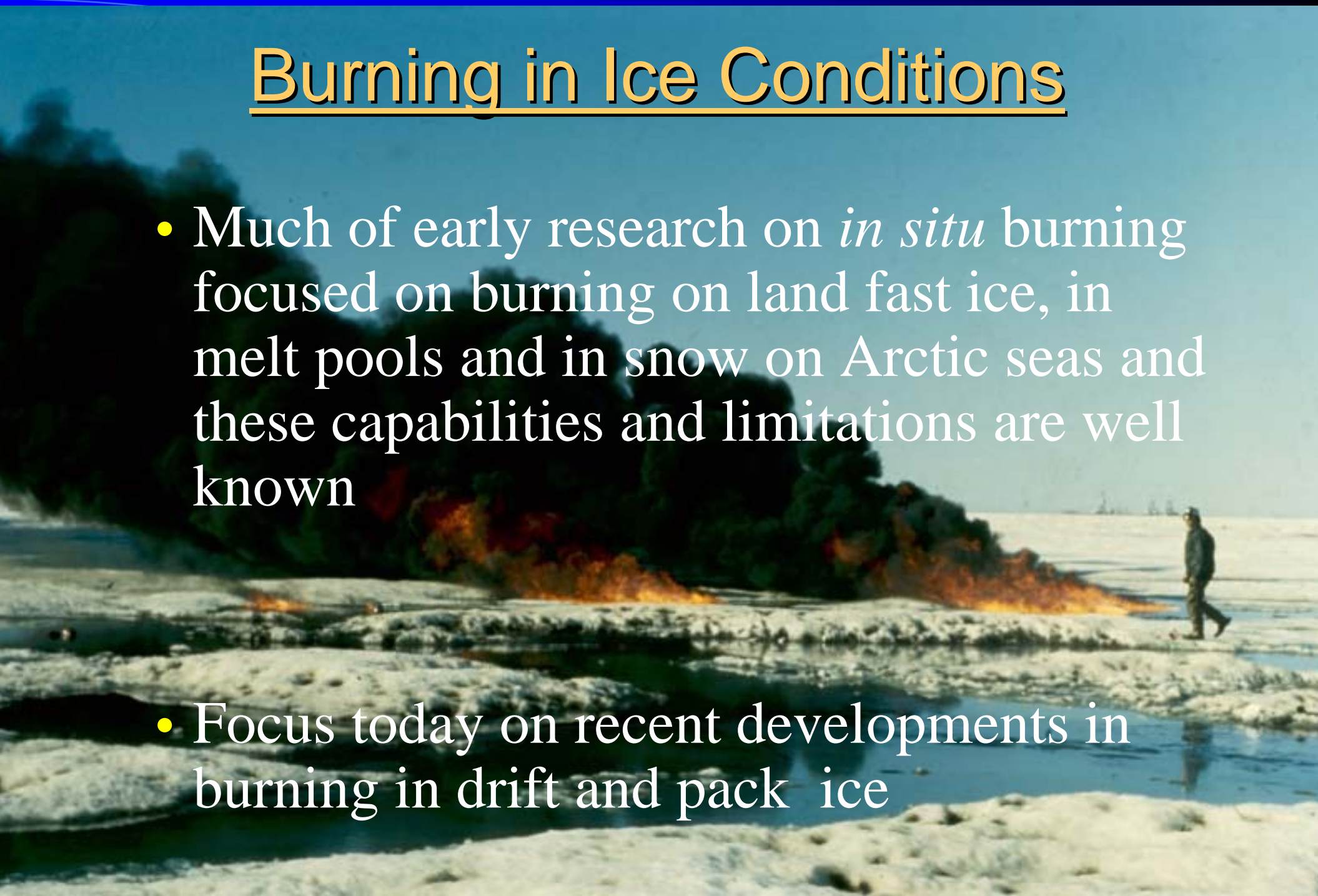
Burning Oil in Snow



- Mixtures containing up to 70% snow (wt) can be easily burned *in situ*
- Promoters effective for lower oil contents
- For still higher snow/lower oil contents can also pile snow into hollow cones and ignite

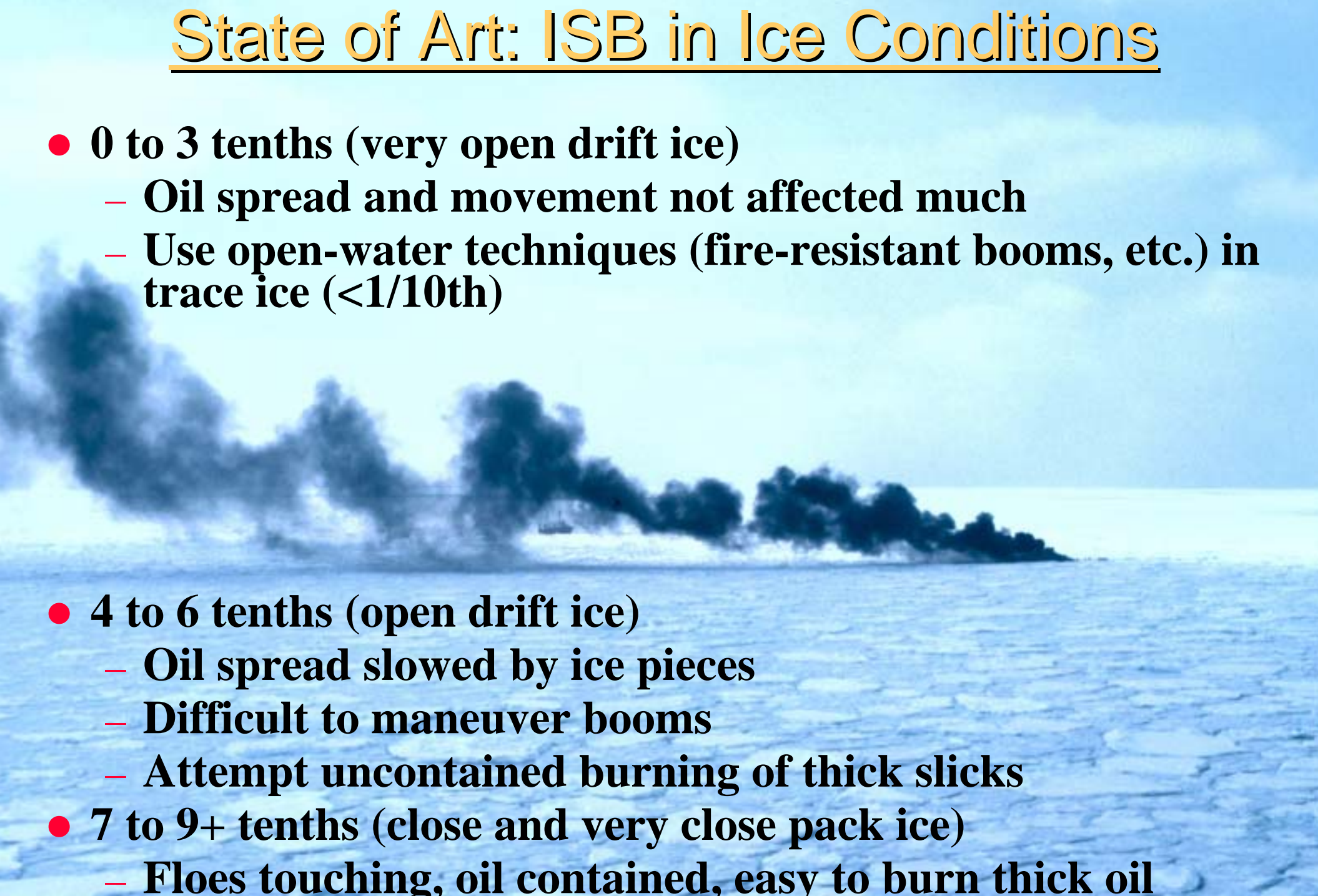
Burning in Ice Conditions

- Much of early research on *in situ* burning focused on burning on land fast ice, in melt pools and in snow on Arctic seas and these capabilities and limitations are well known
- Focus today on recent developments in burning in drift and pack ice



State of Art: ISB in Ice Conditions

- 0 to 3 tenths (very open drift ice)
 - Oil spread and movement not affected much
 - Use open-water techniques (fire-resistant booms, etc.) in trace ice ($<1/10$ th)
- 4 to 6 tenths (open drift ice)
 - Oil spread slowed by ice pieces
 - Difficult to maneuver booms
 - Attempt uncontained burning of thick slicks
- 7 to 9+ tenths (close and very close pack ice)
 - Floes touching, oil contained, easy to burn thick oil



Technology Gap

- Can burn thick slicks in close pack ice (with a timely response)
- Needed to address ISB for thin slicks in drift ice (Rules of Thumb, how to thicken without booms)

Research since 2000 on Thin Slick ISB in Brash and Slush Ice



Rationale

- Previous laboratory and field research studies focused on burning of thick ($\gg 1$ cm) oil slicks in close pack ice.
- For oil spilled in drift ice, field experience has shown that it is the small ice pieces that will accumulate with the oil against the edges of larger ice features or booms and control the local concentration (i.e., thickness) of oil

Research Objective

- To investigate the minimum ignitable thickness, combustion rate, residue amount and the effect of waves for thin oil slicks burned *in situ* on slush ice typical of freeze-up and brash ice typical of break-up
- Focus was on thin oil slicks, such as those that could be generated by blowouts or sub-sea pipeline leaks



Overview

Study consisted of a literature review, small-scale burns in a chilled indoor wave tank in Ottawa and mid-scale burns in an outdoor wave tank at Prudhoe Bay.



Methods

- Four Alaskan North Slope crude oils used for both phases of study.
- Some of the oils were artificially evaporated.
- Tests were designed around two forms of ice:
 1. homogeneous slush ice (also grease or shuga) with very small particle sizes (equivalent to a slurry); and,
 2. a non-homogeneous mix of brash ice with piece sizes up to 30 cm and 10 to 12 cm thick





Methods

- Burn tests were conducted in a medium-size wave tank in Prudhoe Bay in mid-October 2002.
- Burn ring was a 20-foot section of old Shell fire boom formed into a 1.7 m diameter circle.
- Boom held loosely in the centre of the wave tank by wires attached to the side of the tank.











Results

- Test matrix included crude oil type (4), degree of evaporation (for 2 crudes), ice type (brash, slush and o/w) and waves (calm or low swell).
- Calculated burn rate (mm/min) and removal efficiency (weight %).
- Performed 42 burns







Rules of Thumb

The following distills the many lab- and mid-scale results down to simplified “rules-of-thumb” for the burning of thin oil slicks *in situ* on brash or slush ice:

Minimum Ignitable Thickness

- Minimum ignitable thickness for fresh crude on slush or small brash ice is up to double that on open water, or about 1.5 to 2 mm.
- Minimum ignitable thickness for evaporated crude oil on slush or small brash ice can be higher than on open water, but is still within the range quoted for weathered crude on water, about 3 mm, if ignited with gelled-gasoline igniters.

Burn Rate

For a given spill size, the burn rate in calm conditions is about halved on relatively smooth slush ice and halved again on rougher, brash ice. Wave action slightly reduces the burn rate on open water, but the halving rule seems to apply in waves as well.

Removal Efficiency

The residue remaining on brash or slush ice in calm conditions is about 1.5 mm vs. 1 mm on o/w (50% removal vs. 67%). The residue remaining on brash or slush ice in waves is slightly greater than in calm conditions, about 2 mm (33% removal).

Summary

(ISB of Thin Slicks in Brash or Slush Ice)

The combination of the minimum ignitable thickness rule of 3 mm for weathered oil, and the residue thickness rules infers that **3-mm slicks on brash or slush ice can be burned *in situ* with removal efficiencies on the order of 50% in calm conditions and 33% in wave conditions compared to 67% on open water.**

Ongoing Research: Herding Agents to Thicken Oil for ISB in Drift Ice



New Research: SINTEF JIP Oil in Ice ISB



Effective Burning Depends On:

- Thick oil
- Good flame coverage
- Timely response



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